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Identification and characterization of dust source regions across North Africa and the Middle East using MISR satellite observations

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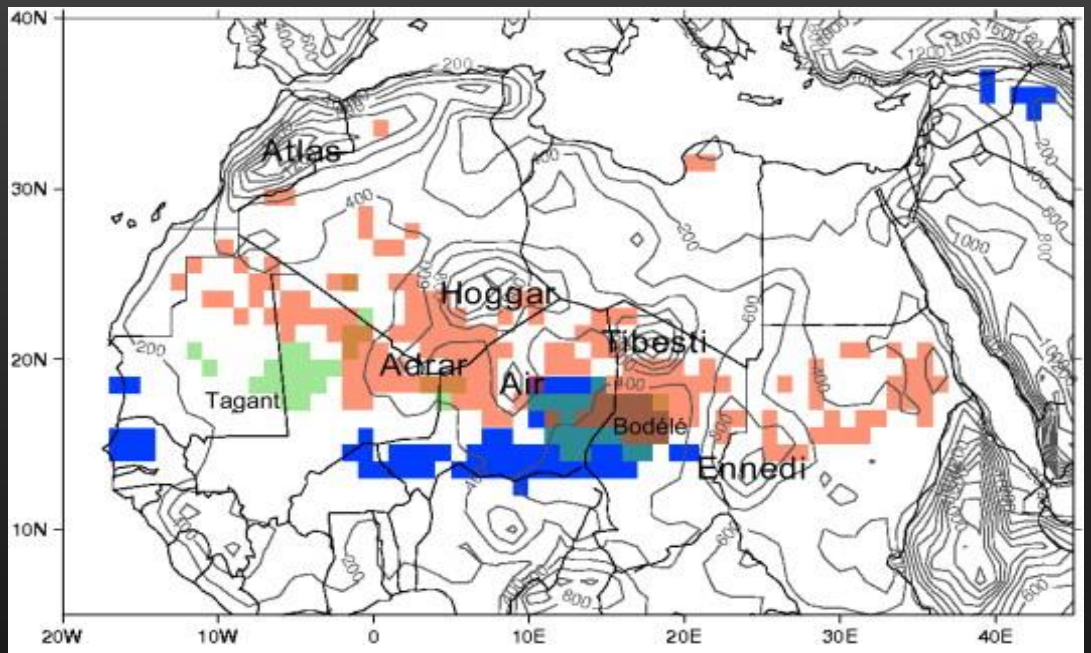
Past studies on dust source identification



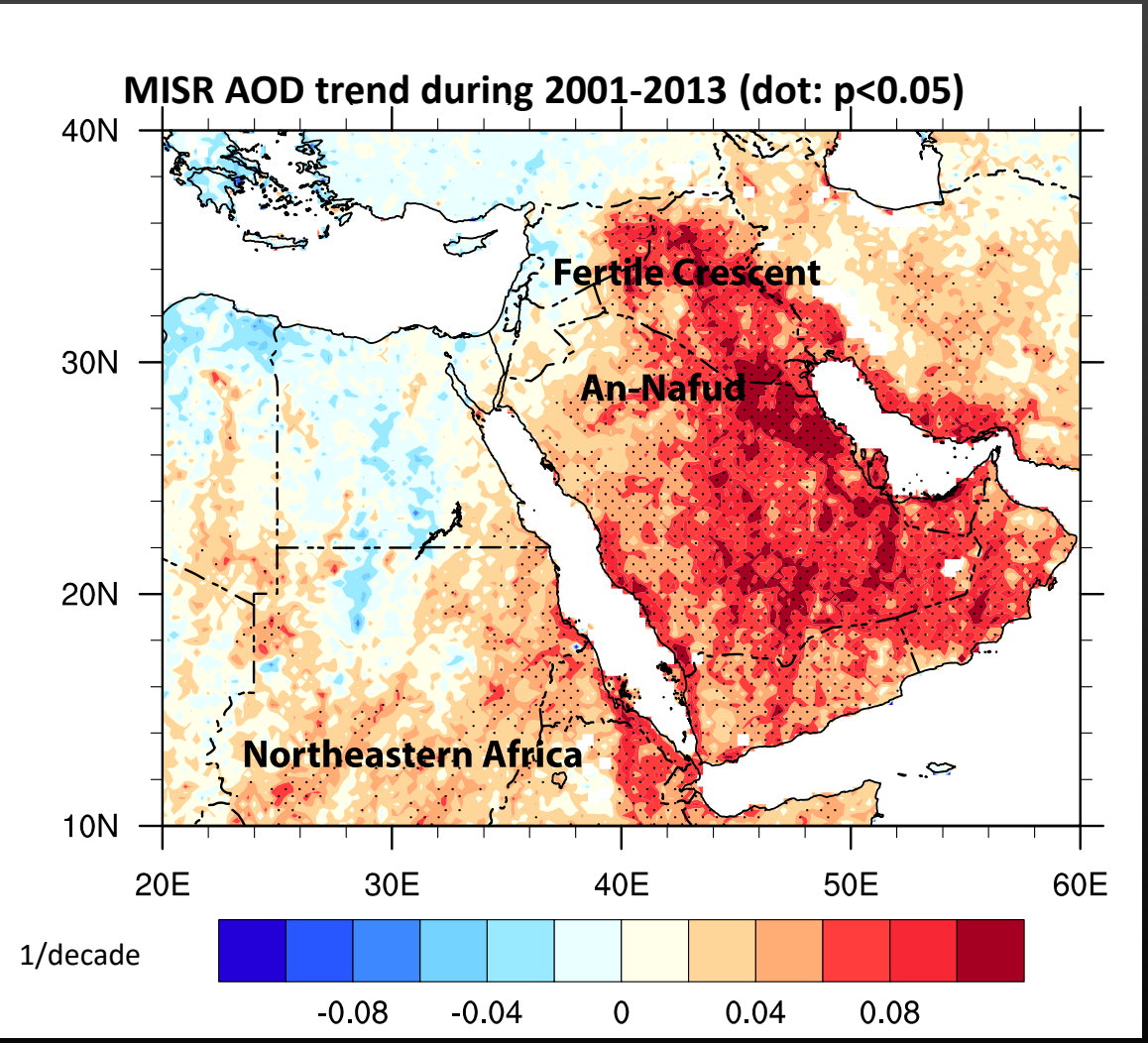
blue—frequency (MODIS DeepBlue AOD > 0.5) > 40%
green – frequency (OMI AI >2) > 40%,
red – frequency (MSG DSA) > 6%,
contour – elevation (m).
(Schepanski et al. 2012)

Previous dust source identification approaches yield different dust source maps (Schepanski et al., 2012), largely due to the limitations in each method and remote-sensing product.

Approach I: based on the analysis of aerosol loadings derived from satellite observations such as daily aerosol optical depth (AOD) from MODIS (Ginoux et al., 2012), or the semi-quantitative aerosol absorbing index (AI) from OMI (Prospero et al., 2002).

Approach II: based on back-tracking of individual dust plumes, namely the Dust Flag (SDF) method (Schepanski et al., 2007; Ashpole & Washington, 2013) from the 15-minute dust index images from MSG SEVIRI.

Trends & interannual variability in dust activities



A substantial increase in AOD over the Middle East since the onset of the 21st century has been revealed from various remote-sensing and ground observations (Hsu et al. 2012; Yu et al. 2015; Notaro et al. 2015; Klingmüller et al. 2016) and reproduced by global aerosol models (Chin et al. 2014; Pozzer et al. 2015).

What is the source of the AOD increase over the Middle East?

Is it really a trend or a segment of long-term variability?

MISR CMVP and non-spherical (dust) AOD

In the cloud motion vector product (CMVP) (Moroney et al. 2002), MISR viewing geometry of the nine cameras is used to simultaneously retrieve motion (wind speed and direction) and top height of moving geometrically thick features, such as aerosol plumes and clouds (mainly dust over the cloud-free North Africa and Middle East). The MISR CMVP is

- geometrically-based, independent of any retrieval assumptions of aerosol optical properties – overcomes the weakness in AI-based dust source identification
- capable of identifying optically thick dust plumes – overcomes the AOD-based and AI-based dust source identification limitations and complements infrared dust-tracking techniques

The MISR nonspherical AOD fraction is often referred to as “fraction of total AOD due to dust”, as dust is the primary nonspherical aerosol particle in the atmosphere, especially over desert regions such as those in North Africa and Middle East (Kalashnikova et al. 2005).

The MISR aerosol (DAOD) and stereo (CMVP) data since 2000 provides a unique opportunity for joint examination of the interannual variability in dust emission and concentration over the broader Middle East and North Africa.

Scientific questions

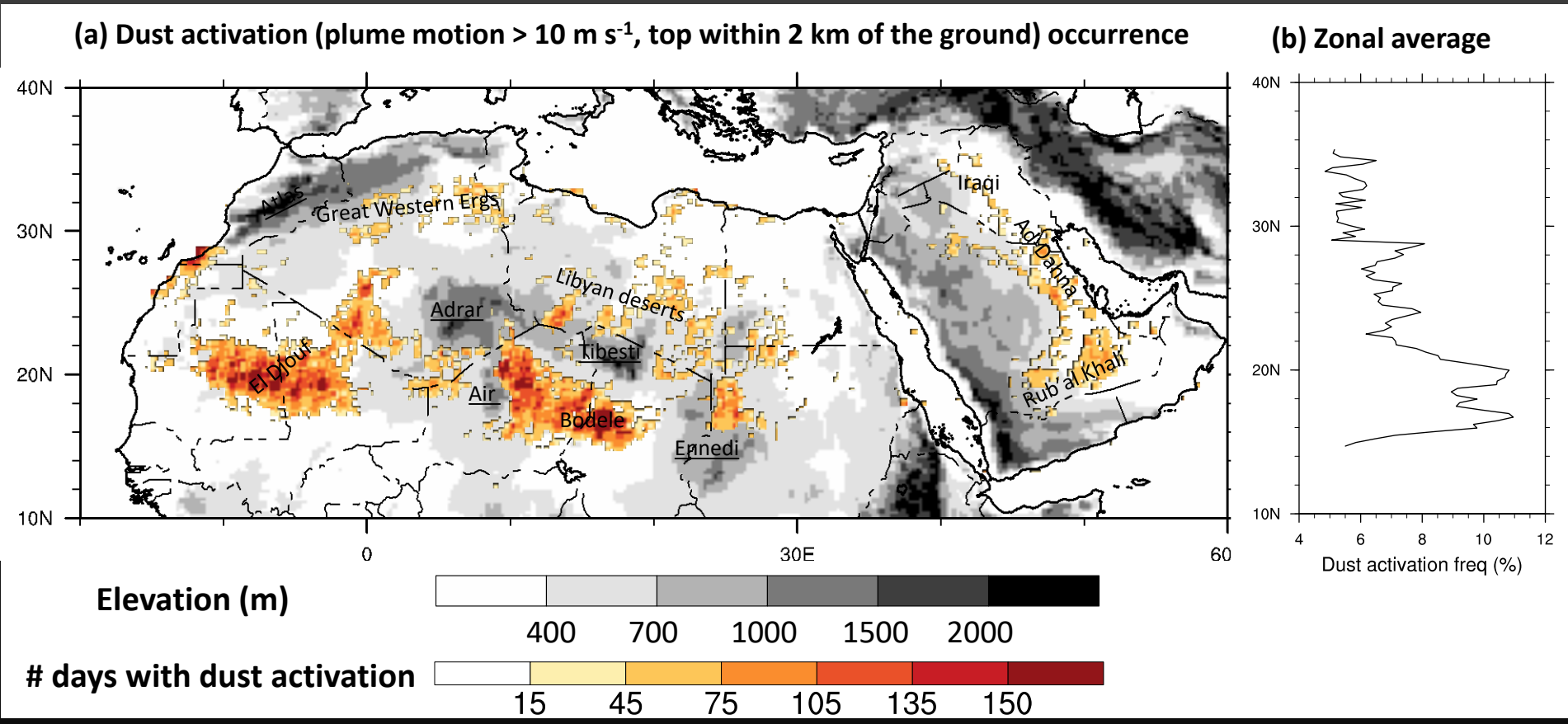
- Where does dust activation occur most frequently across North Africa and the Middle East, according to the novel motion-based dust source identification?
- What climatic features are responsible for the seasonal distribution of dust activation and dust concentration?
- Are there any long-term trends in the dust activation and concentration over North Africa and the Middle East? If so, what are the climatic drivers and effects?

Data

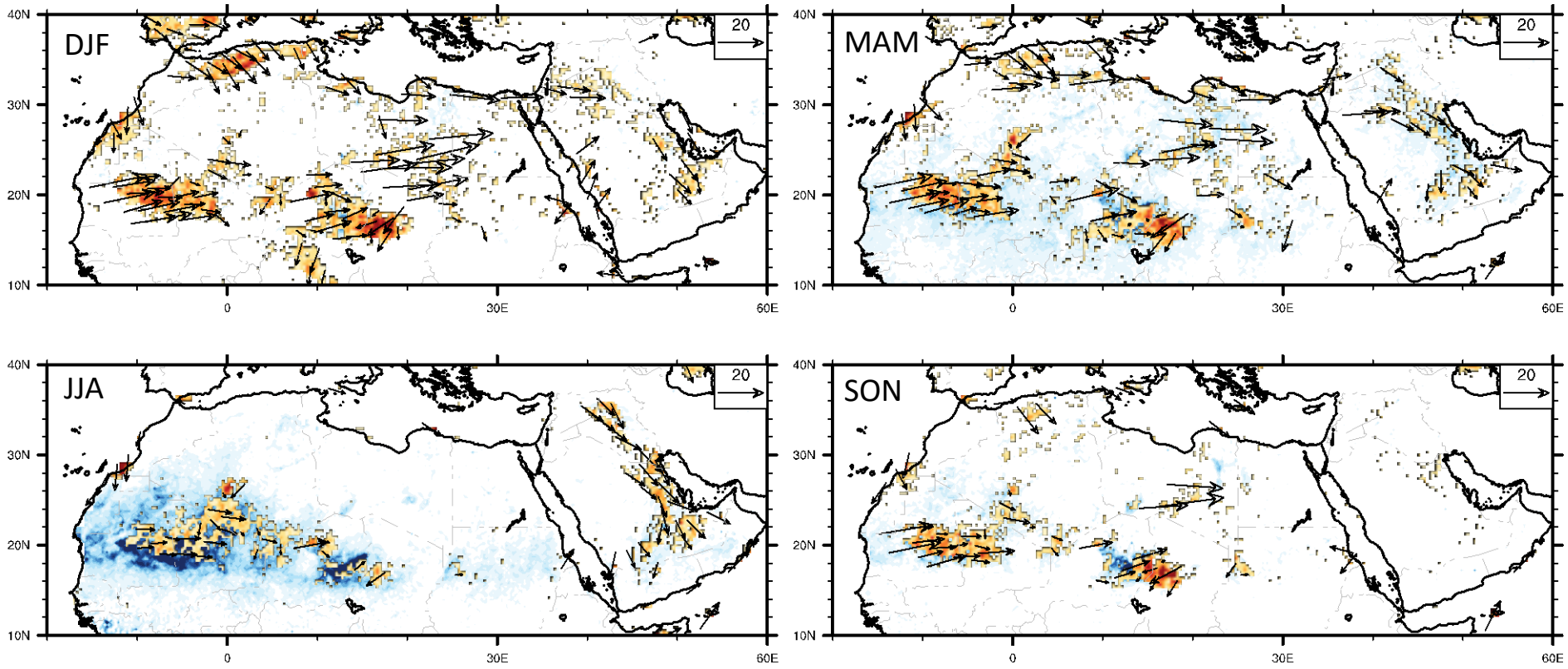
Variable	Dataset	Spatial resolution	Temporal coverage
Dust activation	Version 2, level 2 MISR CMVP	17.6 km	Every 4-5 days in the local morning, with Terra overpass
Dust concentration	Version 22, level 2 MISR DAOD at 558 nm		
Frequency of hourly 10-m wind speed > 10 m s^{-1}	MERRA-2	0.5˚x 0.66˚	Monthly
Precipitation	TRMM Multi-Satellite Precipitation Analysis	0.25˚ x 0.25˚	Monthly
Enhanced Vegetation Index (EVI)	MODIS version 6, level 3	0.05˚ x 0.05˚	Monthly
Land surface temperature	MODIS version 6, level 3	0.05˚ x 0.05˚	Monthly

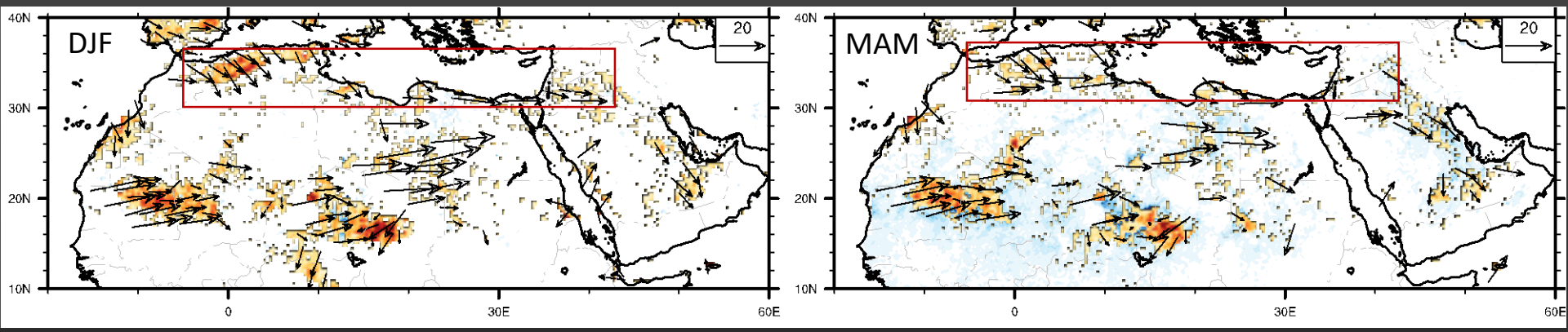
Using MISR CMVP, a “dust activation event” is identified over the study region when the dust plume moves faster than 10 m s^{-1} and the plume top height is within 2 km of the ground.

Dust source regions identified from MISR CMVP



Dust source and immediate transport per season





Sharav Cyclones

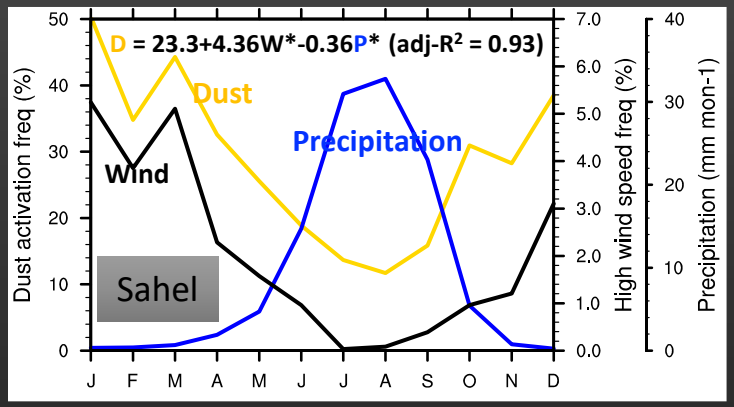
days with dust activation

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 X 50

days with DAOD > 0.49

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 X 160

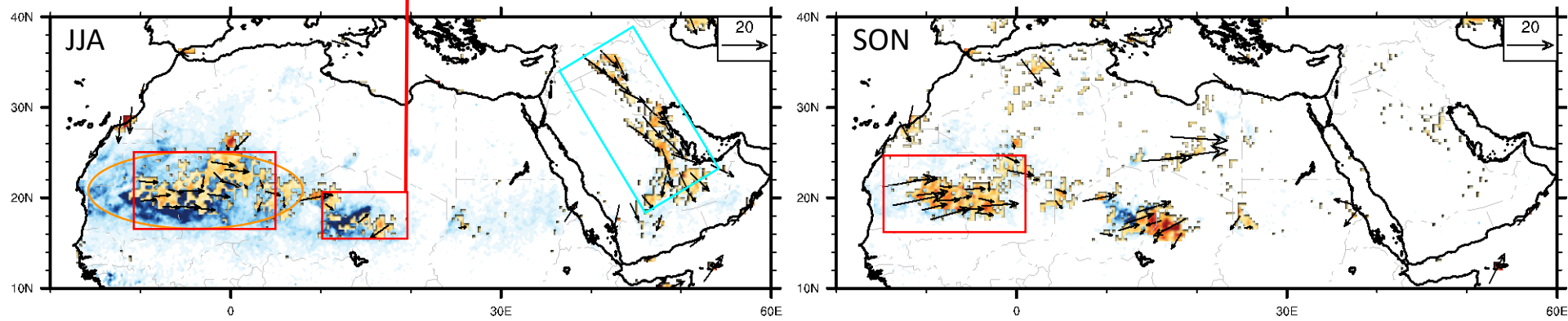
Vector: averaged immediate transport at the plume top (m s^{-1})



Middle Eastern summer Shamal wind

Wide-spread high DAOD over West Africa: long-lived dust due to seasonally enhanced ascending motion

Inhibited dust activation in West Africa and Sahel due to monsoonal wet soils and weakened nocturnal low-level jets, respectively



days with dust activation

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days with DAOD > 0.49

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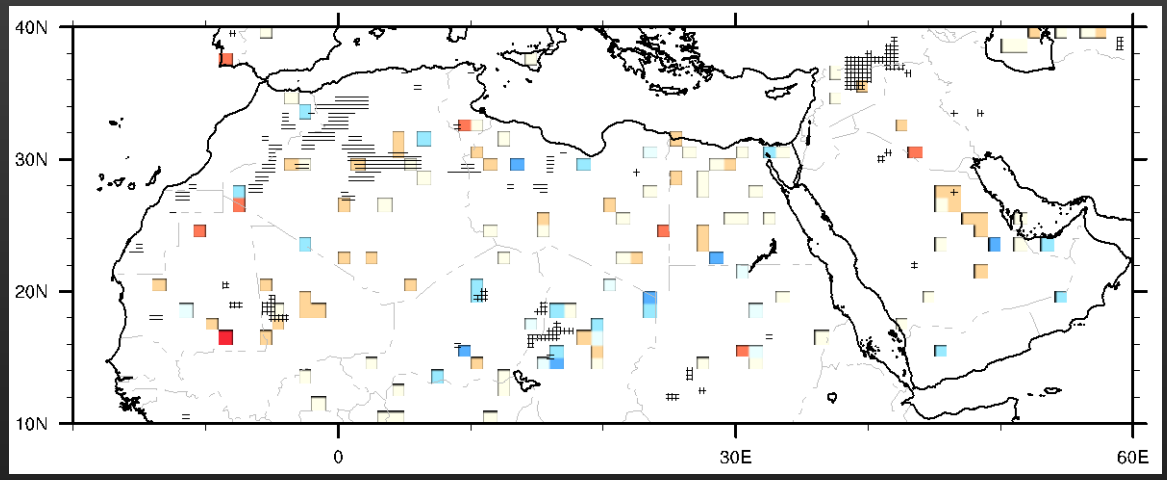
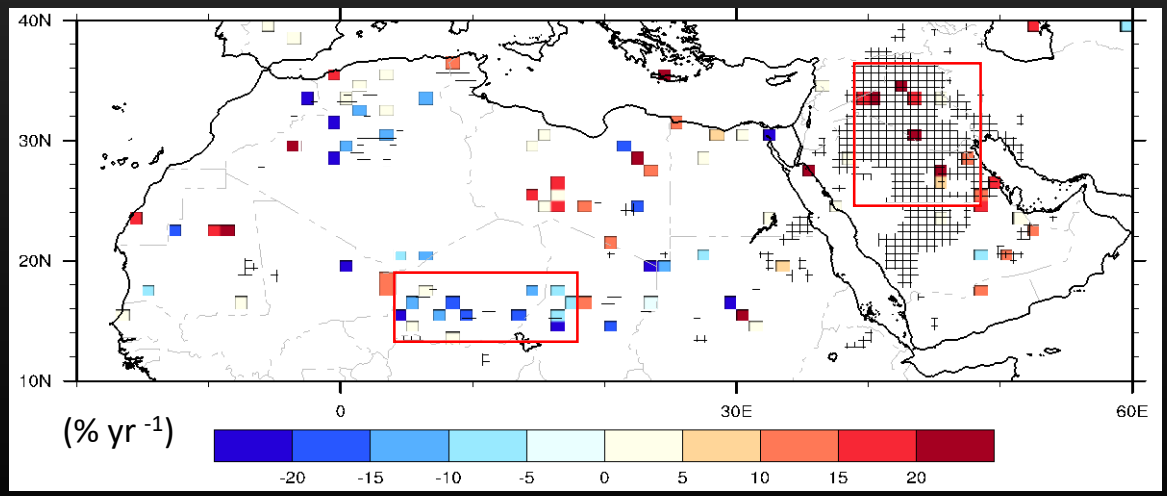
Vector: averaged immediate transport at the plume top (m s^{-1})

Dust activity: trend or interannual variability?

Overall trend in dust activation (color) + DAOD (+ : positive, - : negative) during 2001-2016

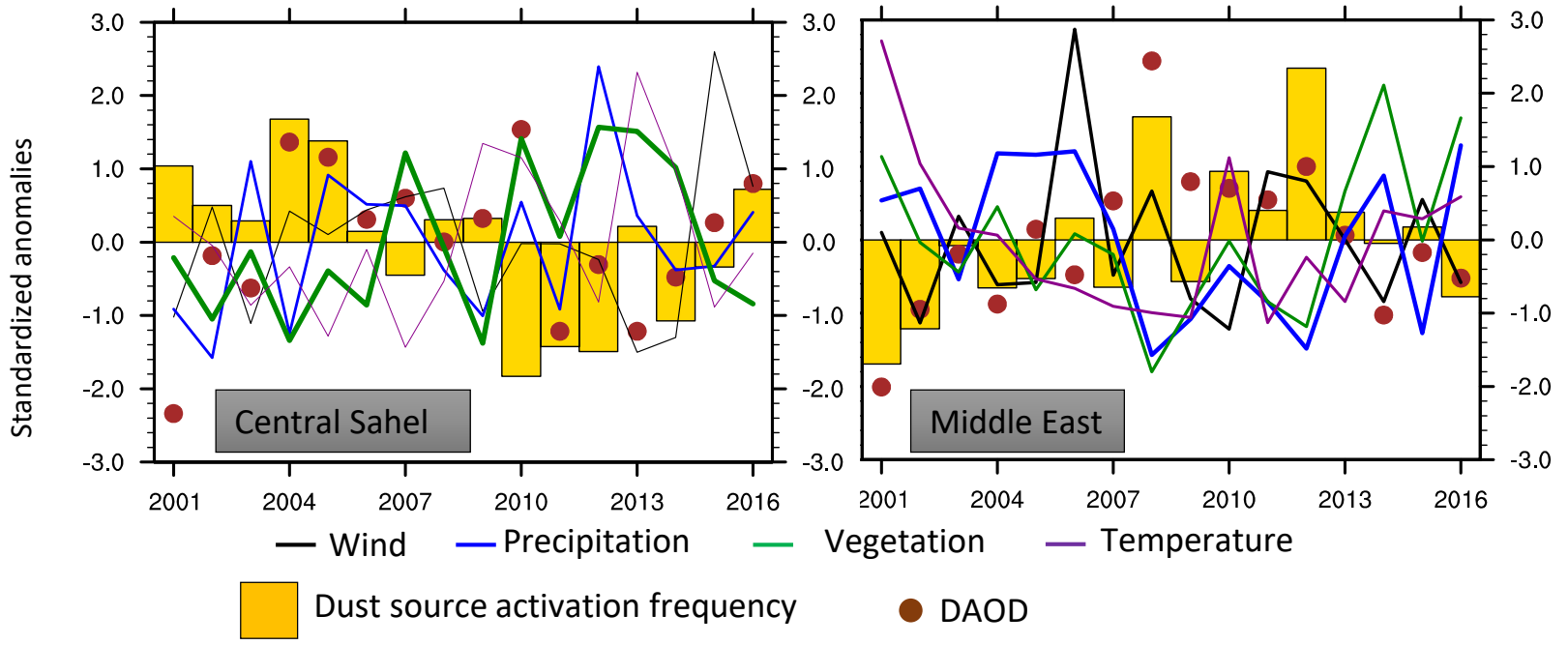


Maximum trend during 10-year periods: 2001-2010, 2002-2011, etc



Only statistically significant trends ($p < 0.05$, according to the Mann-Kendall trend test) are shown.

Dust activity and climatic drivers/impacts



Rank Correlation (*: p<0.05)		Frequency of High Wind Speed	15-month Precipitation	EVI	Temperature
Central Sahel	Source	0.18	-0.48*	-0.75*	-0.11
	DAOD	0.54*	0.15	-0.32	-0.26
Middle East	Source	0.45	-0.60*	-0.52*	-0.40
	DAOD	0.26	-0.71*	-0.82*	-0.64*

Summary

- According to MISR CMVP, dust source regions are generally located in topographical depressions in North Africa and the Middle East, including the Bodélé Depression as the most important dust source. The West African deserts generate substantial dust activities, but are underestimated by the AOD-based identifications.
- Seasonal distribution of dust activation is primarily driven by the climatology in wind and precipitation, highlighting the influence of Sharav cyclones, ITCZ, and Shamal wind on dust activation across the Mediterranean coast, West Africa and Sahel, and the Middle East, respectively.
- According to the joint analysis of MISR CMVP and MISR DAOD, dust emissions and concentrations substantially increased over the Middle East and decreased over the central Sahel during 2001-2012 but partly recovered afterwards.